

Importance of Forage Fish in the California Current



Julie A. Thayer, Ph.D.

Overview



- Definitions
- Forage species ecology
 - Population dynamics
 - Climate and other effects
 - Fisheries effects
 - Predators & their needs

Definitions

CCS forage species

- Small pelagics (*anchovy, sardine, herring, myctophid*)
- Juveniles of predatory fishes (*rockfish, hake*)
- Invertebrates (*krill, shrimp, squid*)

Comprehensive definition

1. Holds key role in the ecosystem
(*is important in predator diet*)
2. Feeds predominantly on plankton
3. Forms dense schools
4. Small size (<30cm)



Forage Species' Ecology

Population dynamics

- Small pelagics' natural population fluctuations
(known, although mechanisms not fully understood)
- Invertebrates are “bugs”
 - *some live <1yr, some longer*
 - *can “shrink & sink”*
- Juveniles depend on adult populations



Climate & Other Effects

-Climate effects

- ENSO, PDO (*warm/cool regimes*)
- Climate change (*trending temperatures, increasing variability*)
 - Ocean acidification
 - Disease, red-tide outbreaks
 - Ecosystem degradation (*pelagic, tidal/subtidal*)

- Species' interactions (*competition, predation, non-natives*)

-Other non-fisheries human influences

- Direct destruction of habitat
- Increased pollution/runoff
- Wave energy generation, desalinization, etc.

Effects of Fishing

- Ecological and population "viability"
 - Forage population declines are due much to climate and some to harvest but causes not separable
 - Fishing makes populations more susceptible to climate (*Hsieh et al. 2006*)



Ultimately, the question is whether fishing has resulted in populations visiting ecological states that would not have occurred naturally.

Who are the Predators?

- Whales & dolphins
- Seals & sea lions
- Seabirds & sea turtles
- Sharks & rays
- Predatory fishes like salmon & tuna



Predator Needs

- Diverse forage base
- Spatio-temporal availability
(predator-prey mis-match more frequent w/ climate change)
- How much food? *(combo of quantification approaches)*
 - Bio-energetic modeling
 - Functional & numerical responses
 - Ecosystem modeling



Top 10 CCS Forage Groups

Forage species	presence in predator diet
Pacific herring (<i>Clupea pallasii</i>)	35%
Lantern fish (Myctophidae)	33%
Codfishes juvenile (Gadidae)	30%
Northern anchovy (<i>Engraulis mordax</i>)	29%
Rockfishes juvenile (<i>Sebastes</i> spp.)	29%
Shrimp (Crangon & Mysid)	25%
Market squid (<i>Loligo opalescens</i>)	24%
Sanddabs, juv. halibuts (Paralichthyidae)	20%
Krill (Euphausiidae)	19%
Pacific sardine (<i>Sardinops sagax</i>)	14%

Forage species	>10%
Anchovy	20%
Rockfishes juv.	19%
Codfishes juv.	19%
Krill	16%
Squid	15%
Lantern fish	15%
Shrimp	10%
Herring	8%
Sardine	7%
Sanddabs	6%

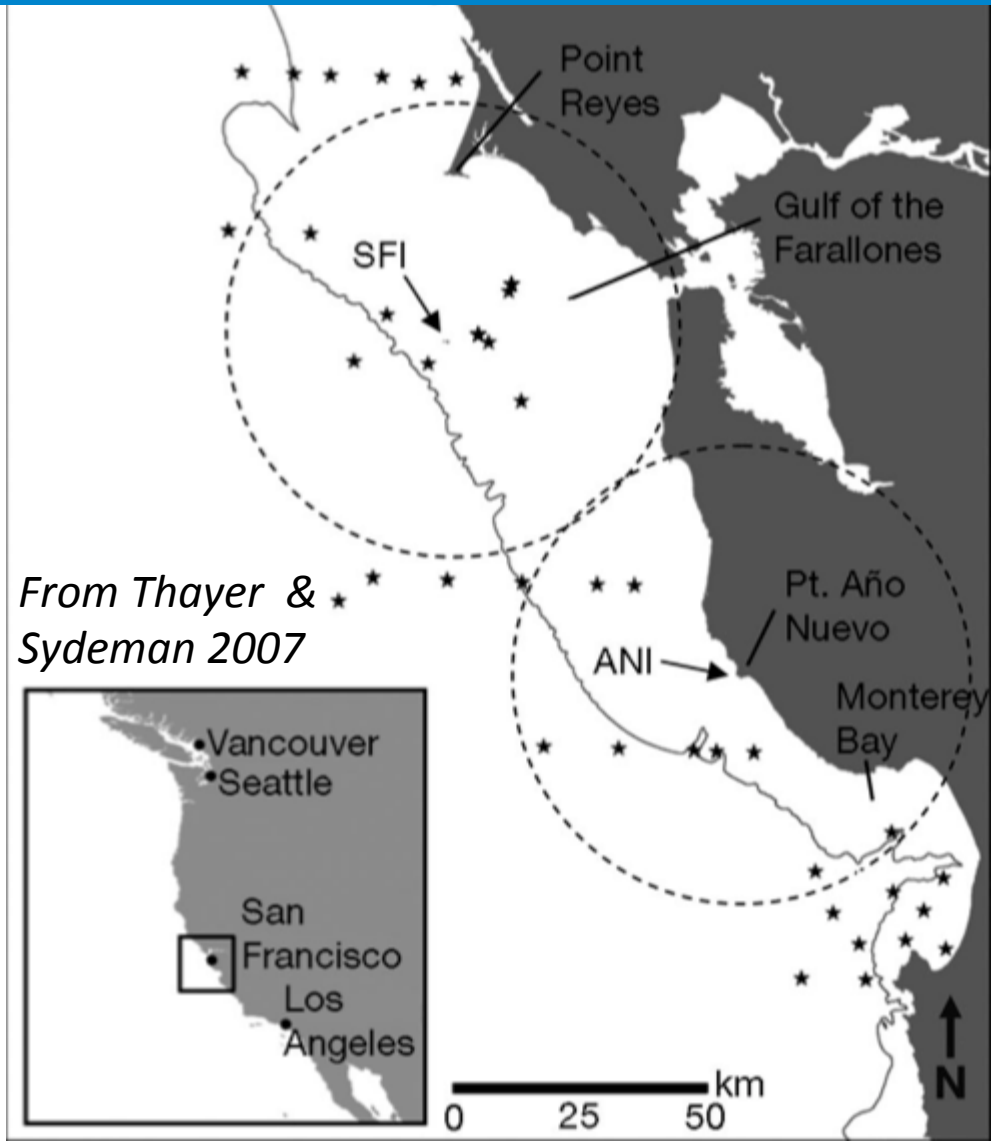
Forage species	>25%
Anchovy	11%
Squid	11%
Herring	10%
Krill	9%
Codfishes juv.	9%
Rockfishes juv.	8%
Lantern fish	5%
Shrimp	4%
Sardine	3%
Sanddabs	2%

Forage species	>50%
Squid	6%
Krill	6%
Anchovy	4%
Herring	3%
Codfishes juv.	3%
Rockfishes juv.	2%
Shrimp	1%
Lantern fish	0.6%
Sardine	0.6%
Sanddabs	0.6%

Local Prey Importance

Important breeding colonies in Central CA
(13 seabird, 5 pinniped spp.):

- Southeast Farallon Island
(~100,000 birds & 6,000 pinnipeds)
- Año Nuevo Island
(~9,000 birds & 18,000 pinnipeds)

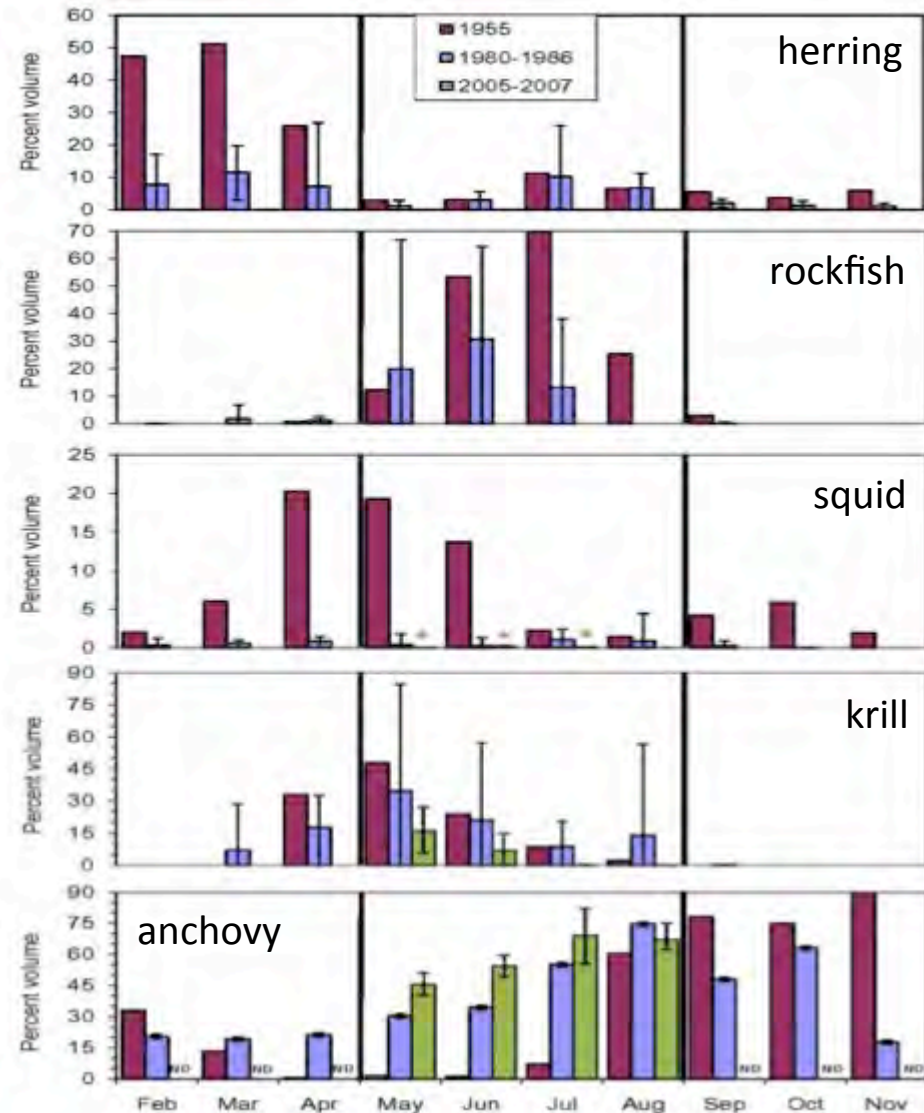


Seasonal Prey Importance

Central CA Chinook salmon diet



From Thayer et al. submitted



Inter-Annual Prey Importance

Predator	N (years)	Source	Percent of prey in diet between years								
			Krill	Market squid	Anchovy	Sardine	Herring	Rockfish (juv.)	Gadid (juv.)	Myctophid	Sanddab
Brandt's cormorant	9	Ainley et al. 1981		0-0.2	0-28		0-73	0-91	0-15		
California sea lion	3	Weise and Harvey 2008		5-19	7-13	61-68	0.2	3-6	2-6		0-2
Chinook salmon	11	Thayer et al. submitted	0-48	0-20	1-90	0-28	0-51	0-70	0-7		0-1
Common murre	4	Matthews 1983	0-36	0-15	0-47		1-24	1-43	9-30		0-11
Elegant tern	8	Velarde et al. 1994			35-98	2-59					
Pacific hake	2	Livingston 1983	0-93		0-16		0-67	0-4	0-1.3		0-1
Rhinoceros auklet	17	Thayer & Sydeman 2007		0-27	8-100	0-18	0-8	0-61	0-1	0-12	
Sooty shearwater	2	Gould et al. 2000	0-1	0-2	36					1-40	
Yellowtail rockfish	2	Brodeur and Pearcy 1984	0-28	2-15			0-18	0-0.4		0-3	

Bio-energetic modeling

Seabird prey needs – *Common Murre*

- Pt. Conception, CA to Cape Blanco, OR
- Estimated prey consumption (2004) = **225,235t**
- Included consumption of:
 - ~58,000t market squid
 - ~55,000t juvenile hake
 - ~23,000t anchovy
 - ~21,000t juvenile rockfish

From Roth et al. 2008

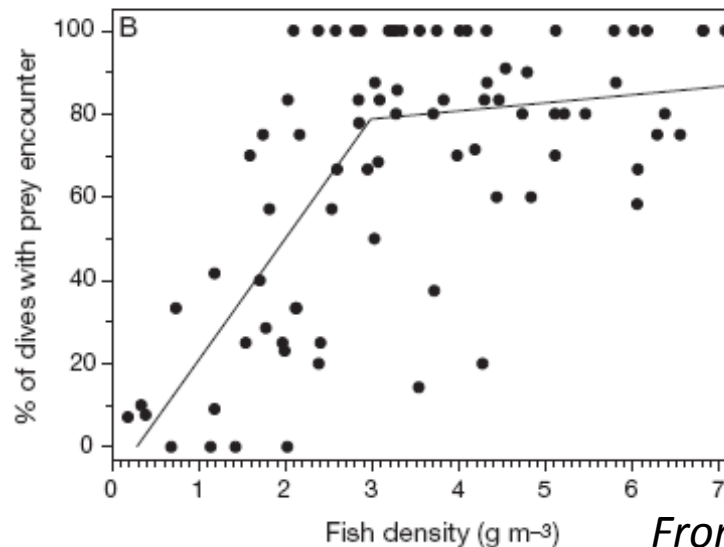


Functional Responses

- Single predator parameter vs. forage parameters
- Determines threshold at which predator parameters are compromised



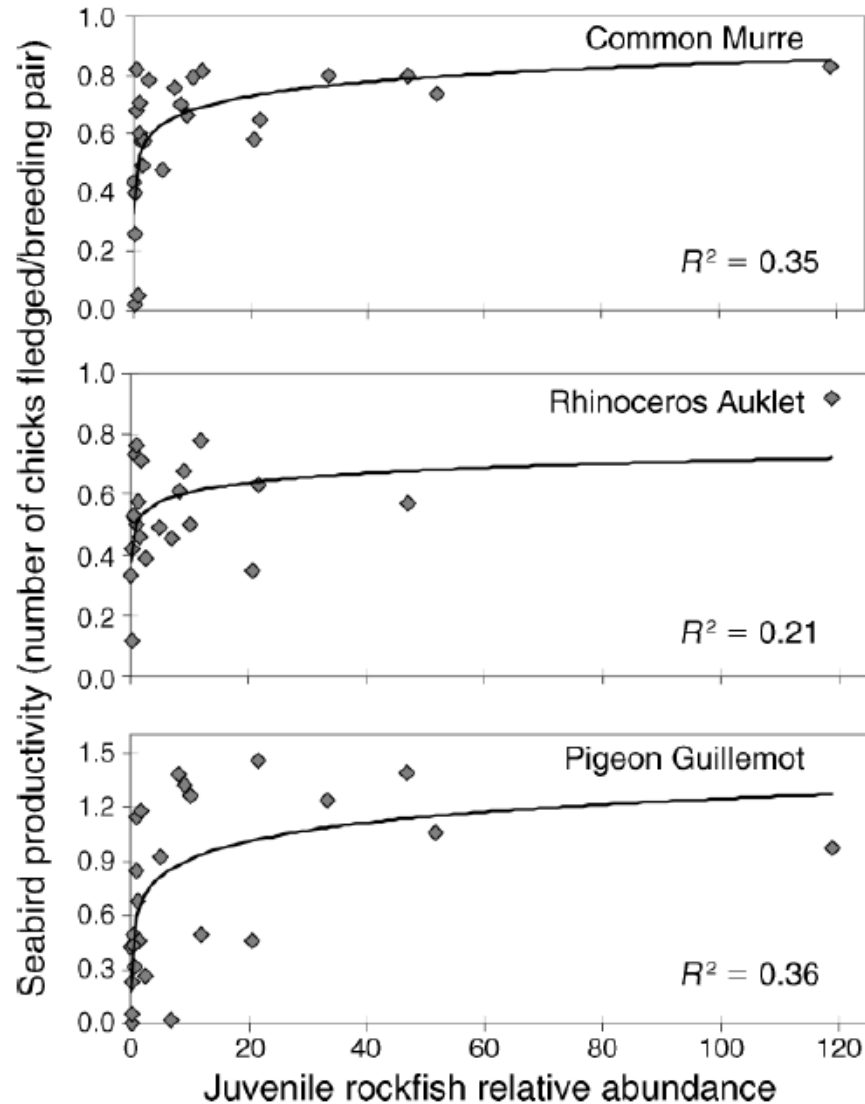
Double-crested cormorants and juvenile rainbow trout



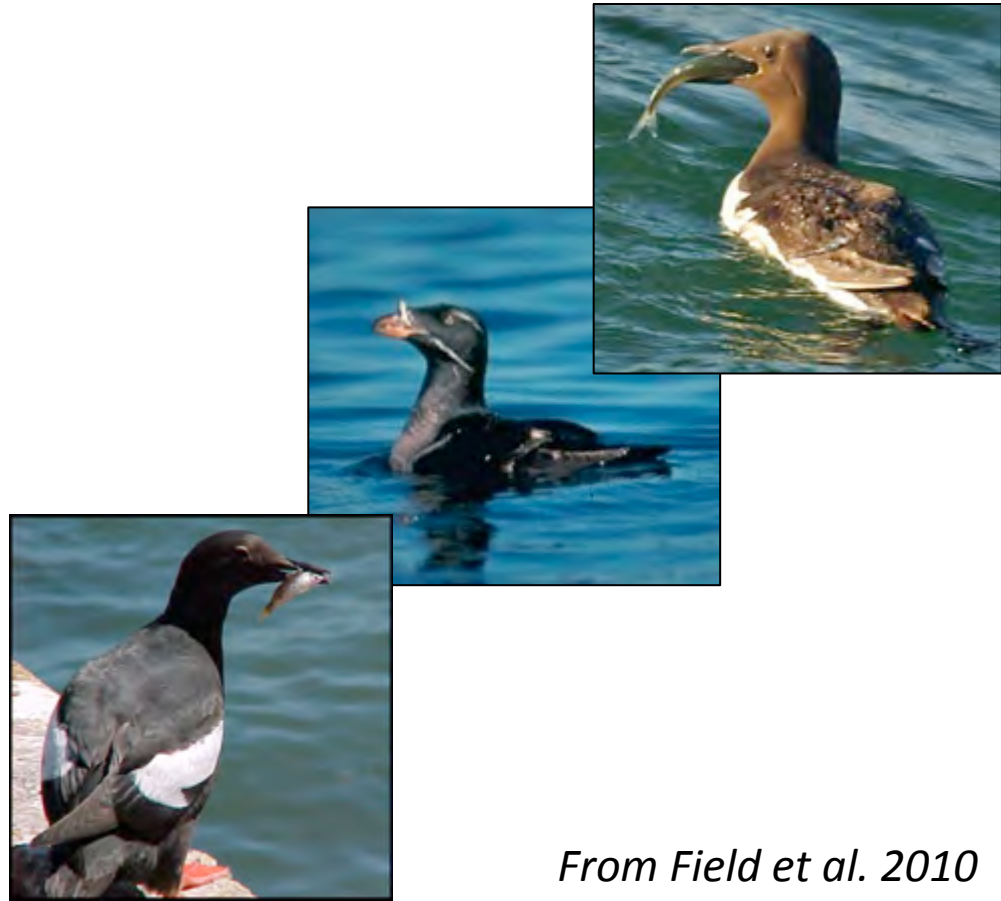
Below threshold, likelihood of bird encountering fish decreased

From Enstipp et al. 2007

Numerical Responses – CCS Data

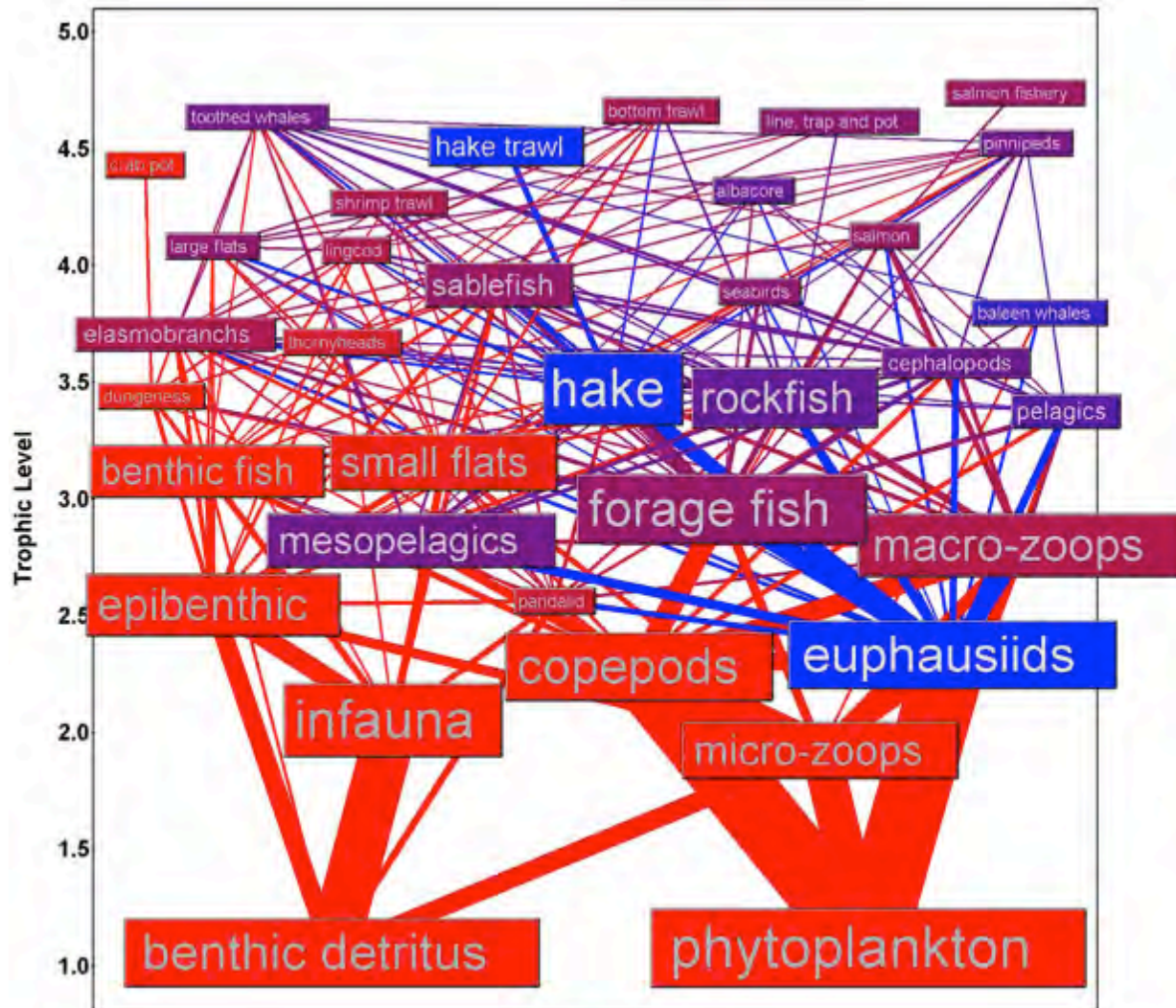


Seabird productivity
and prey abundance



From Field et al. 2010

Ecosystem modeling – current



- Allows integration of multiple predators in a comprehensive ecosystem context
- ECOPATH w/ECOSIM, ATLANTIS
- But has NOT been able to replicate population cycling of coastal pelagics

From Field & Francis 2006

Ecosystem modeling - needs

- Stochastic models best represent predator use of prey
(which varies seasonally, inter-annually, spatially)
(e.g., End-to-End Models: ROHMS->NPZ->IBM)
- Get away from abundance as metric of predator response
(the LEAST responsive measure, may underestimate needs)
- Incorporate variance *(averages do not accurately represent how predators respond to prey availability)*



Ecosystem-Based Approach

- Many of top 10 forage groups in the CCS are exploited
- Ecological importance of forage species is not new issue, but improved acknowledgement and explicit management guidance needed
(particularly in light of increasing climate variability)
- First step - data does exist to quantify predator forage needs in the CCS – needs synthesis!



Summary

- Forage species are more than just small pelagics
- Forage species ecology affected by climate & fishing
- Whales to seabirds rely on these forage species
- Important to have diverse forage community
(species richness, space & time)
- Data exist to quantify predator needs;
need to be synthesized
- Ecosystem-Based Management

